Chapter 1

Genesis: 1957–1961

GOLDSTONE, CALIFORNIA

A fine, wide, blacktop road runs past the salt-encrusted bed of dry lake toward the Mars site at Goldstone, deep in California's Mojave Desert. Opposite the lake bed off to the right, a disused minor road leads through a narrow cleft in the desiccated, brown and brick red-colored landscape to another dry lake bed, surrounded by low, barren hills and also encrusted with dried salt. There is nothing else here except for a small brick building and an unusual, spidery, three-legged structure supporting a large, perforated metal dish. The open side of the dish faces the sky, and high above its center, a smaller dish is suspended at the apex of four tall struts protruding from the surface of the large dish. Although the immensity of the totally barren landscape dwarfs the whole structure, it is, in fact, well over thirty meters to its highest point. A chain link fence encloses the area, and a bronze tablet on the nearby stone marker informs the occasional visitor that this is the site of the NASA Pioneer Deep Space Station. The inscription on the plaque, overlaid on the photograph of the Pioneer site shown in Figure 1-1, identifies the station's association with the NASA space program.

Figure 1-1. View of the Pioneer tracking station site, Goldstone, California, 1978. The road entrance to the site is on the far side of the picture, while the antenna, seemingly diminished by the immensity of surrounding landscape, stands in the center near the edge of the lake bed.

Figure 1-2. Prominent personalities of the Deep Space Network unveiling the commemorative plaque at the Goldstone Pioneer Site, 28 October 1978. Eberhardt Rechtin, principal founder of the Deep Space Network, is on the right. William H. Bayley, the original General Manager of the Network, is on the left. Richard K. Mallis, DSIF Operations Manager, is standing next to Bayley. Charles Koscielski, Director of the Goldstone Complex at the time of the dedication ceremony, is next to Rechtin.

Several of the people who played a prominent part in the establishment of the original Network attended the dedication ceremony. They appear in the unveiling picture shown in Figure 1-2. Their role in the chronicle of the Deep Space Network (DSN) will become apparent in later chapters.

This antenna, built in 1958, known through most of its working life as Deep Space Station 11 (DSS 11), was the first antenna in what eventually became the NASA Deep Space Network. As the inscription of the plaque implies, it supported all of the NASA deep space missions during the twenty years of its operational life.

At deactivation in 1981, Station Director Lou Butcher sent a message to his colleagues throughout the Network which neatly summarized the Station's long association with the NASA space program: "The closing of the Pioneer (DSS 11) station marks the end of 23 years of spaceflight tracking. DSS 11 was built when the Jet Propulsion Laboratory

(JPL) was under contract to the Army and was the first 26-meter antenna to be built in the DSN. DSS 11 was the leader for all DSN stations to follow in tracking the first JPL space mission (*Pioneer 3*) in December 1958. It was the station that tracked *Surveyor 1* onto the Lunar surface, and the station that tracked the lunar module (*Apollo 11*) onto the Lunar surface. It has played a major role in most of the NASA Lunar and Planetary spaceflight achievements." The United States Department of the Interior designated the Pioneer site as a National Historic Landmark on 27 December 1985. In a very literal sense, this is where the history of the Deep Space Network began.

The International Geophysical Year (IGY)[1], 1957, a cooperative international enterprise to advance the state of scientific knowledge about Earth and its environment, commenced in July and was running its course. In October, the Russians launched the world's first Earth-orbiting satellite, called *Sputnik*, as part of their contribution to the IGY activities. About a month later, Soviet scientists launched a larger version of *Sputnik* containing a live dog, named Laika, into a high elliptical orbit around the Earth. Both in and out of government, scientific, and engineering circles, the effect of the *Sputnik* launch was one of complete surprise, followed by damaged pride and embarrassment. From a military viewpoint, the implications were obvious: the Soviets demonstrated an operational, intercontinental ballistic missile (ICBM) capability ahead of the United States. While to the scientific world at large, Soviet science was clearly leading the "race to space," the hopes of U.S. scientists were pinned on Project Vanguard, a U.S. Navy project to place a grapefruit-sized scientific package in Earth orbit. In full view of a national television audience, the first Vanguard launch at Cape Canaveral in December 1951 was a complete failure, enhancing even more the prestige of the Soviet accomplishment with Sputnik.

The U.S. government was engaged in a desperate "catch-up" game with its Soviet counterpart in the newly emerging field of space research.

The events that followed the December Vanguard debacle are the stuff of which the history of JPL is made, but to properly appreciate what happened next, one needs to make a short backtrack to 1955.

As a consequence of a lengthy experience with the U.S. Army as a contractor on various guided missile development programs at the White Sands Missile Range, JPL had already developed a great deal of expertise in the techniques and technology of guidance and tracking systems for large rockets and ICBMs. While working for the Army as long ago as 1955, JPL, in competition with the Navy and the Air Force, submitted a proposal for an Earth-orbiting satellite for the U.S. contribution to the IGY. JPL's satellite was to be called Orbiter. The Department of Defense (DOD), however, selected the Navy's proposal called Vanguard, and JPL's Orbiter proposal was shelved. Perhaps it was serendipity, but the U.S. Army encouraged JPL to continue with development of Orbiter, at a low level, for the next couple of years. High-speed upper stages for the booster rockets were developed and guidance and telemetry systems were designed and tested. Of particular significance to the then-distant future of a deep space tracking network was the tracking system designed by JPL to track the high altitude test rockets. It was called Microlock, and working in conjunction with a minimum weight radio transmitter carried by the flight test unit, could provide telemetry and positional data to a range of several thousand kilometers. A phase-lock tracking receiver, a key feature developed at JPL by Eberhardt Rechtin and Richard Jaffe some years earlier, was operational at each of the Microlock stations.

Toward the end of 1957, perhaps sensing that the Vanguard program was in trouble, Secretary of Defense Neil H. McElroy authorized the Army to reactivate the Orbiter program and proceed with all deliberate speed to an earliest possible launch. The Army provided a launch vehicle based on an existing Redstone rocket design and JPL provided a suitable satellite carrying a small scientific payload, including a radiation-measuring instrument designed by Dr. James A. Van Allen of the University of Iowa. The satellite was renamed Explorer and the Army-JPL team was committed to launch in 90 days.

To track the new satellite and to receive its downlink telemetry signals, JPL expanded its existing Microlock ground-based tracking facilities to include stations at Cape Canaveral; Singapore; Nigeria; and San Diego, California. Primitive communications services to the overseas sites sometimes relied on native "runners" to transport messages and tapes to the nearest telegraph office. Although the U.S. stations had interferometric tracking antennas, a single, helical antenna at each overseas site provided only telemetry and Doppler data. Primitive though it was, JPL had acquired its first taste of worldwide network development and operations.[2]

On 31 January 1958, less than 60 days after the Vanguard explosion on the launch pad, and just 84 days after receiving approval from Secretary McElroy, *Explorer I* lifted off the launch pad at Cape Canaveral atop a Juno I launch vehicle and, to the acclaim of a national television audience, became America's first Earth-orbiting satellite. Telemetry data received by the Microlock ground stations from the Van Allen Geiger-counters revealed the presence of a high altitude band of radiation encircling Earth. Eventually named for Van Allen, this became one of the most important discoveries of the IGY.

Suddenly, the "catch-up" roles of the previous year were reversed and JPL never looked back. Henceforth, attention was focused not on the near-Earth region but outward, toward deep space, and its chief advocate was the ambitious and far-sighted director of JPL, William H. Pickering.

Knight Commander of the British Empire, conferred by England's Queen Elizabeth II in 1975, is among the many honors and citations bestowed upon William Pickering by prestigious scientific and technical organizations throughout the world. Knighthood not only recognized his scientific achievements, but also symbolized his British heritage and association with his native country of New Zealand. Pickering received his formal high school education in Wellington, the capital city of New Zealand, prior to embarking on a career in electrical engineering at California Institute of Technology (Caltech) in Pasadena, California, in 1929. Seven years later, he had earned a Ph.D. in physics and an appointment to the Caltech faculty, where, in addition to teaching, he was engaged in cosmic ray research with Robert A. Milikan and H. Victor Neher.

During World War II, Pickering organized and taught electronics courses for military personnel at Caltech, and became acquainted with the Radiation Laboratory at MIT and its director, Lee A. Dubridge. By the time Dubridge was named to the presidency of Caltech in 1946, Pickering was working at Caltech's Jet Propulsion Laboratory on the design and development of telemetering systems for rocket research vehicles. Pickering was appointed director of JPL in 1954 and immediately began moving the laboratory toward the forefront of applied engineering research and development. Within a few short years, the results of this move became apparent to the world-at-large in a spectacular way. The *Explorer I* Earth-orbiting satellite, the United States' initial response to the Soviets' *Sputnik*, made its appearance in January 1958, thanks to the combined efforts of the teams led by Pickering (satellite), von Braun (launch rocket), and Van Allen (radiation measuring experiment).

Following this spectacular success, historian Cargill Hall described Pickering as, "spare, intense, reserved, and in a quiet way, implacable . . . determined to mount a JPL program of lunar flights. To his mind," he said, "lunar flights might once have been a subject fit only for science fiction, but now they were on the reachable frontier of engineering science, exactly the frontier where Pickering wanted JPL to be." Prophetic words indeed. As director of what soon became a NASA Field Center, Pickering led JPL through the highs and lows of the first U.S. spaceflights to the Moon, and later, to Venus and Mars. Under his leadership, NASA/JPL, part of which included the Deep Space Network, quickly established and maintained a position of pre-eminence in the emerging, new art of science and technology for deep space planetary exploration.[3]

He retired from JPL in 1976 and served for two years as director of the research institute of the University of Petroleum and Minerals in Saudi Arabia. He later returned to Pasadena to enter private consulting practice.

The Pioneer Lunar Probes

On 7 February 1958, responding to President Eisenhower's initiative for a United States Space Program, the Department of Defense established an organization called the Advanced Research Projects Agency (ARPA) to promote, coordinate, and manage all existing military and civilian space activities. ARPA was to function only as an interim organization pending congressional establishment of a civilian space management agency.[4]

Toward the end of March 1958, the Secretary of Defense announced approval of a lunar space program, to be directed by ARPA as part of the United States' participation in the International Geophysical Year (IGY) activities. The program was named Pioneer.

The Pioneer lunar program involved three launches by the U.S. Air Force, using an existing Thor-Able booster rocket combination, and two U.S. Army launches utilizing the new Jupiter Intermediate Range Ballistic Missile (IRBM), designated as Juno II. The scientific objectives of the Pioneer program were to measure cosmic radiation in the region between Earth and the Moon, and to make a more accurate determination of the mass of the Moon. At the same time, valuable experience in the design of a lunar probe trajectory and a tracking and telecommunications system could be obtained. Because of its long prior association with the Army's missile development programs at White Sands Missile Range, JPL was to be involved in the two Army launches, *Pioneers 3* and *4*. The target launch dates were set for 11 November and 14 December 1958.

Research into the tracking and communications systems required to support a space program of lunar and planetary spacecraft had been in progress at JPL for some time.

Confronted with the problem of tracking and communicating with the two Pioneer probes, JPL put that fund of knowledge to good account.

At that time, JPL was fortunate to have, as the head of its small missile guidance research division, a visionary whose advocacy of the long term approach determined the course of U.S. solar system exploration far into the future.

Tall, imposing in appearance, of quiet disposition and authoritative manner, Eberhardt Rechtin was the epitome of the top-level executive. Articulate, with a brilliant engineering mind, he seemed to be way ahead of other the speaker in a conversation, or the presenter at a conference. He was patient with those less acute in their thinking, and courteous in pointing out errors of fact or judgement. A dark suit and tie completed his picture. He was also, not surprisingly, an accomplished violinist.

Eberhardt Rechtin brought a B.Sc. degree in electrical engineering (1946) from the California Institute of Technology with him when he joined JPL in 1946 as a member of the very talented communications and radio guidance team on the Corporal and Sergeant programs. He completed a Ph.D. in electrical engineering at Caltech in 1950 and along with Richard Jaffe, went on to study the theory and design of "phase-lock" circuits. With Walt Victor's help, the basis of the "phase-lock" receivers became an integral part of the DSN.[5]

As the first head of the Tracking and Data Acquisition Office at JPL, it was Rechtin's vision of a worldwide network of tracking stations, and his considerable powers of persuasion and tenacity in pursuing his ideas with NASA, that gave impetus and direction to the DSN in the early formative years. It was his endorsement that gave substance to the far-reaching proposals of Victor, Stevens, and Merrick for the new 64-meter antennas that would be much larger and perform better than any existing antennas designed for tracking distant spacecraft. He introduced the concept of the "sum of the negative tolerances" as the standard criterion for the margin of safety in the design of uplinks and downlinks for planetary spacecraft. To control the electrical interfaces (uplink and downlink) between the DSN and the many different JPL and non-JPL designed spacecraft that he perceived would require tracking support from the DSN in the years ahead, he mandated fixed, definable specification for the DSN radio links. This would become a permanent and vital feature of DSN management in the years ahead.

Father of the phase-lock loop and architect of the DSN were his legacies. Rechtin retired from JPL in 1967 to head the Advanced Research Projects Agency of the U.S. Department of Defense.

It was the perception of Eberhardt Rechtin that solar system exploration should continue to evolve in coming years and eventually become a major part of the overall NASA space program. He envisioned not only a lunar program which included soft landings on the Moon's surface, but also a program that involved a photographic survey of Venus and Mars.

A long-range vision such as his required not one, but three antennas spaced at 120 degrees of longitude around Earth so that they could maintain continuous contact with the spacecraft as Earth rotated about its axis. Although time and funding precluded the full-scale plan, for the immediate task of tracking the Pioneer lunar probes, one antenna sufficed. It did not allow for continuous contact with the probe, but the time of launch and trajectory could be arranged so that the actual flyby occurred when the probe was in view of the single antenna site. Later, assuming approved appropriate funding, the additional antennas could be added to create the full network and give the U.S. the capability to communicate with future spacecraft travelling to the edge of the solar system.

To lend credence to his ideas, Rechtin gathered experts in all the fields of technology necessary to accept a challenge of those dimensions.

Victor, Stevens, Merrick, and Bell, each an expert in his own field, had the knowledge and drive to lead the way in developing and building the super-sensitive receivers, telemetry and guidance systems, high power transmitters and large precision antenna structures, all needed on a very short time scale.

Immediate decisions were needed on basic communications parameters, such as operating frequency, antenna gain, antenna diameter, beamwidth, angular pointing accuracy, slew rate, receiver sensitivity, Doppler tracking rates, bandwidth, transmitter power, and signal-to-noise ratios. Similar parameters were needed for the probe radio system so that the probe and Earth communications systems continued to work together as the distance between them stretched as far as the Moon and beyond.

The team had already determined that the existing ground-based tracking systems, which were being used by JPL for the Earth-orbiting Explorer flights in progress at that time, were not suitable for tracking lunar probes. A more efficient, high-performance, Earth-based antenna was needed. After considerations of antenna gain, automatic tracking performance, minimum galactic radio noise and the state-of-the-art radio communications at that time, a frequency of 960 MHz was chosen as near-optimum for the communications link between the lunar probe and Earth. The Pioneer radio transmitter transmitted at 960 MHz and the Earth-based tracking station received on that frequency. A large-diameter, steerable, parabolic dish antenna capable of operating at 960 MHz was needed to receive the transmissions from the Pioneer probes and be available for the support of possible follow-on missions, perhaps even for missions beyond the Moon to the nearest planets. The launch dates were set for yearend. Cost and construction time were vital factors in the search for a suitable antenna. While incorporating advanced and reliable principles of design, the antenna was to be built and operating in approximately six months.

The choice of 960 MHz as the operating frequency for the Pioneer probe brought with it another most significant advantage. It allowed JPL to make use of an existing design for a large radio astronomy antenna developed some years earlier for the burgeoning science of radio astronomy by the Naval Research Laboratory, with assistance from the Carnegie Institute, Associated Universities, and the Blaw-Knox Company. As a result of this prior work, the Blaw-Knox Company could provide a large parabolic antenna that would meet the fixed price and construction time constraint of six months. The antenna, 26 meters (85 feet) in diameter, was designed for radio astronomy applications, and required substantial modifications to the antenna drive system to make it suitable for precision tracking of lunar space probes.

Confident in JPL's ability to make the necessary changes and get the antenna built and operating in time for the Pioneer 3 launch, ARPA decided to purchase not one, but three, of the 26-meter antennas. One of the antennas would be used for the imminent Pioneer launches, while the other two were intended for ARPA longer range plans for what it termed its World Net. It was a calculated risk on the part of ARPA, for even though the design was complete, none of the antennas had yet been built. With the pressure of the Pioneer launch schedule, however, there was little choice in the matter.

With the operating frequency and antenna decisions already made, attention turned to a location for the antenna site. To avoid contaminating or obscuring the very weak radio signals received from the distant spacecraft with artificial radio interference, a location remote from any metropolitan area was desired. At the same time it needed to be close enough to an established community to be practical for the staff that would be required to operate the equipment. The combined constraints of funding and schedule strongly influenced a search for a suitable site on Government-owned property. A convenient location that met all of these criteria was found in a natural bowl-shaped area surrounded by low hills near the Goldstone Dry Lake on the Fort Irwin military reservation, 72 kilometers northwest of the city of Barstow, in the Mojave Desert, California.

In March 1958, a JPL radio interference survey team certified the area as free from radio interference. A month later a construction company began work on access roads, facilities, services, and buildings. While work was in progress at Goldstone, a mobile tracking station, using a three-meter diameter antenna, was erected near Mayaguez, Puerto Rico to obtain initial trajectory data downrange from the Florida launch site.

In early June, the steel components for the antenna started to arrive onsite at Goldstone. Assembly of the antenna commenced in mid-August and was completed in November 1958. By that time, all the receiving, recording, communications, servo, and antenna drive modifications and other electronics had been installed and tested. After a short period of crew training, the station was ready for its first operational mission, but there had been no time to spare. A photograph of the first Goldstone antenna, as it looked shortly after beginning operation in 1958, is shown in Figure 1-3.

While the antenna construction work was proceeding on an accelerated schedule at Goldstone, the direction of the space program was changing rapidly in Washington. President Eisenhower's Executive Order No. 10783 officially established the National

Figure 1-3. The 26-meter antenna and tracking station (DSIF 11) at Pioneer site, Goldstone, California, 1958. Pioneer, the first Goldstone antenna as it looked shortly after beginning operation in 1958. The antenna was deactivated in 1981 and has been designated a National Historic Landmark by the U.S. Department of the Interior.

Aeronautics and Space Administration (NASA) on 1 October 1958. Discussions regarding the status of the Jet Propulsion Laboratory and its possible acquisition by NASA as a component Field Center quickly followed.

NASA outlined its proposal for the transfer of JPL from the Army on 15 October 1958. A few weeks later, the Department of Defense indicated acceptance of the proposal and on 3 December 1958, Presidential Order No. 10793 transferred the functions and facilities of the Jet Propulsion Laboratory of the California Institute of Technology from the Department of the Army to NASA.

NASA launched *Pioneer 3* on a trajectory toward the Moon three days later, on 6 December 1958. Due to a rocket booster problem, the probe only reached an altitude of 63,500 miles before falling back to Earth, somewhere in central Africa. The small antenna in Puerto Rico tracked it for 14 hours (round-trip) and was able to maintain telemetry contact to at least 60,000 kilometers. The much larger Goldstone antenna was able to acquire telemetry for the entire time that the *Pioneer 3* probe was above its horizon. The telemetry received from the Puerto Rico station proved to have significant scientific value because it contained the data from two passes through the then-mysterious Van Allen radiation belts.

Although the *Pioneer 3* flight was a disappointment, three months later, the next lunar probe, *Pioneer 4*, became the first United States spacecraft to leave Earth's gravitational field. Launched on 3 March 1959, on a trajectory similar to that of *Pioneer 3*, the probe traveled 435,000 miles toward destination before its batteries became depleted and its transmissions to Earth ceased. After 41 hours of flight, *Pioneer 4* passed 37,300 miles from the Moon's surface on a flight path that was a good deal ahead of and below the planned trajectory. Although one of the key experiments to observe the hidden side of the Moon was defeated by the perturbed trajectory, data from the onboard radiation counters identified a third belt of radiation and sensed significant changes in the intensity of the Van Allen radiation belts discovered by *Pioneer 3*. With its large antenna working well, the Goldstone station recorded over 24 hours of telemetry data from three successive 10-hour passes over the site, before the signal ceased during the fourth pass on 6 March 1959.

While the *Pioneer 3* and *4* missions had not been entirely successful, the performance of the new antenna exceeded all expectations. It demonstrated the efficacy of its design and fully vindicated the confidence that ARPA had shown in JPL's expertise and ability to accomplish a challenging task. It would henceforth be known as the Goldstone Pioneer tracking station, identified as DSIF 11.

The Echo Balloon Experiment

Important and highly visible as they were, the *Pioneer 3* and *4* lunar probes were not the only projects that engaged the attention of Rechtin and his engineering team at JPL in the spring of 1959. In January, JPL had agreed to cooperate with NASA and Bell Telephone Laboratories (BTL) of Holmdel, New Jersey, in an experiment to test the feasibility of long-range communications between two distant points on the surface of the Earth by means of a reflected signal from the surface of a large orbiting balloon. Based on separate

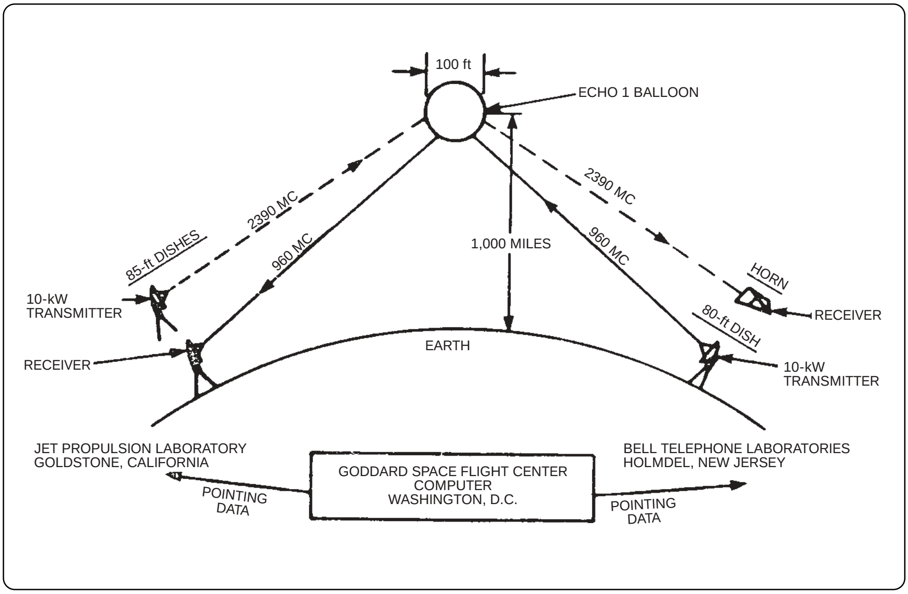

Figure 1-4. Essential features of the Project Echo Experiment, 1960.

and independent proposals from scientists at BTL, who were interested in studying the use of "passive repeaters" for radio communications, and scientists at the Langley Aeronautical Laboratory in Hampton, Virginia, who were interested in air density measurements in Earth's upper atmosphere, this experiment, named Project Echo, was endorsed several years earlier by the United States IGY Committee. Scientists had agreed on a design for an experiment to satisfy both scientific objectives. A radio signal would be transmitted from the east coast of the United States, reflected off the metalized surface of a large (100-foot diameter) Earth-orbiting balloon, and received on the west coast. A similar link, using a much higher frequency, would be set up in the west-to-east direction. The plan called for setting up separate links at 960 MHz (east to west) and 2,390 MHz (west to east). The essential features of the experiment are shown in Figure 1-4.

In the fall of 1958, while considering how the Echo balloon experiment might be implemented, it became apparent to engineers at JPL that the new antenna, then under construction at Goldstone, could serve as the west coast receiving terminal for the 960-MHz, east-to-west leg of the experiment. For its part, BTL would provide a 960-MHz transmitting station and a 2,390-MHz receiving station at its east coast facilities in New Jersey. However, one major problem remained unsolved. There was no transmitter for

Figure 1-5. Az-El transmitting antenna for the Echo Balloon Experiment, Goldstone, 1960. The antenna was constructed between July and December 1959, and the complete station became operational in July 1960.

the 2,390-MHz for the west-to-east leg of the experiment. The new Goldstone antenna was designed as a receiving station only. It had no transmit capability.

To solve that problem, a second 85-foot antenna was built at Goldstone in 1959 using funds provided by the NASA Communications Satellite program. To avoid mutual radio interference between the two antennas, a site some miles away but similar to the Pioneer site was selected. A low range of hills separated the two sites and provided the necessary level of radio isolation between them. JPL named the site "Echo" for its obvious association with the Echo experiment.

An early photograph of the transmitting antenna at the Goldstone Echo site is shown in Figure 1-5.

Unlike the Pioneer antenna, which used a polar or hour angle-declination (HA-Dec) drive system, the Echo antenna used a high-speed, azimuth-elevation (Az-El) drive which was more suitable for tracking Earth satellites, such as Echo, than the more astronomyoriented polar drive used for deep space probes. The Echo station also included a 10-kilowatt transmitter operating at 2,390 MHz, which at the time represented a very advanced, state-of-the-art development. In addition to supporting the Echo balloon experiment, the advanced features of the Echo station allowed JPL engineers to evaluate the relative merits of large antenna drive systems and the performance of high-power transmitters and low-noise receivers, operating at S-band, for future applications in deep space tracking stations.

Less than a month after the full station was completed, on 12 August 1960, *Echo 1* was launched. Within two hours of launch, a recording of President Eisenhower's voice was transmitted from the Echo site at Goldstone to BTL in New Jersey. Echo had scored a "first" in long distance passive reflector communications. Ironically, this distinction was almost immediately eclipsed by the informal Goldstone to Woomera "moon-bounce" experiment described later in this chapter. Experiments in long distance communications and upper atmospheric air density soon followed.

At the conclusion of the Echo experiment, ownership of the Echo antenna was transferred to the new NASA Office of Tracking and Data Acquisition and became an official part of the Deep Space Instrumentation Facility. Its ultimate destiny, however, lay in a different direction from that of Pioneer, the other DSIF antenna at Goldstone. The first step along this path began with the Venus Radar Experiment in March 1961.

The Venus Radar Experiment

The possibility of detecting an Earth-based radio signal reflected from the surface of Venus had intrigued radio astronomers through most of the 1950s. In fact, investigators at Lincoln Laboratory, Massachusetts Institute of Technology, and at Jodrell Bank Experimental Station, University of Manchester, had attempted to detect echoes from Venus in 1958 and 1959 without success.

A successful experiment of this kind could offer great potential for a plethora of new scientific knowledge about Venus and its physical properties, and the possibility, for example, to determine the reflective properties of the surface for electromagnetic radiation, the orientation of the planet's axis of rotation, and its rate of rotation. Also, much could be learned about the characteristics of the interplanetary medium along the transmission path between Earth and Venus. Most importantly though, it could offer the possibility to independently determine a value for the astronomical unit (AU) with much greater accuracy than had been previously possible.

The astronomical unit (AU), used by astronomers as a measure of the mean distance of Earth from the Sun, is a vital parameter in the calculation of the ephemerides, or the paths of planets around the solar system. It was therefore of immense significance to JPL's long-range plans for sending spacecraft on missions to close encounters with distant planets. JPL engineers viewed the Venus radar experiment as a technological challenge for the type of equipment required for future missions to the planets and for personnel to operate it. Without the very highest level of performance in both areas, the hope for success would be minimal, and would establish a standard against which the performance of future operational DSIF stations could be judged.

During the experiment, a 13-kilowatt, continuous wave, S-band signal was transmitted from the new Echo antenna toward the planet, while the reflected signal was received by the Pioneer antenna fitted with a Maser receiver, specially designed for reception of very weak signals. The first undisputable radar returns from the planet Venus were obtained with the Goldstone radar on 10 March 1961. Using advanced, spectrum analysis techniques, the radar team, led by Richard Goldstein, measured the delay to, and changes in, the fundamental character of the returned signal due to its round-trip to Venus and back to Earth. These data were recorded for subsequent scientific analysis. During the time that Venus remained within 50 and 75 million miles from Earth, over 200 hours of good radar data were obtained.

After analysis, this impressive bank of scientific data yielded the much sought after "improved value for the AU" in addition to satisfying the several other scientific objectives of the experiment. The new value for the AU was determined to be 149,598,500 ± 500 km, a most significant improvement in the accuracy of previous values.[6] Subsequently, JPL estimated that *Mariner 2*, the first mission to Venus the following year, would have missed the planet by too great a distance to have been of any scientific value, had the old value of the AU been used in the trajectory computations.

The Venus radar experiment thus represented the first use of the DSN (DSIF) as a scientific instrument. Its immediate success marked the appearance of a significant astronomical research tool at Goldstone, whose stature in the scientific community would continue to rise as the years went by. The technical details of the Venus radar experiment, and the history of what evolved into the Goldstone Solar System Radar, is described in chapter 8, "The Deep Space Network as a Scientific Instrument."

Research and Development Antenna

By the time the Venus radar experiments ended in May 1961, it had become apparent that JPL communications engineers needed a dedicated antenna research and development facility at Goldstone, where new components used in the network could be tested, measured, and evaluated. With the pressing needs of future missions in mind, and the Ranger and Mariner missions about to start, it was simply not possible to devote one of the two existing Goldstone antennas (Pioneer or Echo) solely to research work, despite the vital importance to the technological future of the network. Predictions of future mission requirements mandated a need for two operational antennas, not only at Goldstone, but also at the other two longitudes.

Furthermore, until a way could be found to simultaneously transmit and receive on a single antenna without severely degrading the downlink signals, two antennas, one for transmitting and the other for receiving, would be required for deep space communications.

On this basis, the case was made for yet another antenna at Goldstone. The new antenna, which would be of the same type as the Pioneer and two overseas antennas, would be erected at the Echo site where it could make use of the existing support facilities. When that was completed, the original Echo Az-El antenna would be moved to another site a few miles away, and established as the basis for a new facility dedicated to deep space communications research and development (R&D).

The plan was rapidly approved by NASA and immediately put into effect at Goldstone. Between February and May 1992, a new HA-Dec antenna was erected near the Az-El antenna at the Echo site. It was put into service two months later, just in time to support the first Mariner missions to Venus.

With a second operational deep space station now in place at Goldstone, the Az-El antenna could be released from network support and prepared for the complex task of relocation.[7]

In June 1962, the entire Az-El antenna—mounted on its pedestal—was jacked up, loaded on a supporting undercarriage, and moved approximately four miles across the desert to a new location that became known as the Venus site, after the now famous Venus radar experiment. There, the antenna began a brilliant new life as a test facility for communications research and development, and over the next 40 years, proved vital to the continued preservation of JPL pre-eminence in the field of deep space communications.

The research work that was conducted at that facility, known through the DSN R&D Station 13, is described in chapter 7, "The Advance of Technology in the Deep Space Network."

WASHINGTON, DC

Before proceeding further with the history of the DSN, it will be instructive to review the events occurring simultaneously in a related but quite different arena from that just described. The focus of that activity was in Washington, DC.

Before NASA was created, ARPA had planned to develop a worldwide network of tracking stations to support its forthcoming programs for the exploration of deep space. The network was to be called Tracking and Communications Extraterrestrial Network (TRACE). Starting with the first three TRACE stations—Goldstone, Puerto Rico, and another small station at Cape Canaveral—ARPA planned to expand TRACE into a full-scale worldwide network by adding two additional overseas stations, similar to the one it had funded for Goldstone. This expansion was the rationale for the ARPA decision to purchase three of the 85-foot-diameter antennas from Blaw-Knox in 1957.

Plans for the worldwide network were well under way in early 1958. ARPA had already approved a JPL proposal for a three-station network which would provide optimum coverage for tracking deep space probes. One of the sites would be sites at Goldstone, California. The two overseas stations were to be located at Luzon, the Philippines, and in Nigeria.[8]

Taking a broader view, however, the Department of Defense expressed some reservations about the proposed sites in terms of their utility to all U.S. space vehicles, rather than the specific, deep space probes considered by JPL. With this in mind, ARPA asked JPL to reconsider its proposal for the station sites with the object of improving coverage for a broader range of space vehicle trajectories. The resulting study showed that better orbital coverage for all planned U.S. space missions would be possible if the Nigerian site was moved north to southern Portugal or Spain, and the Philippines site moved south to central Australia. The coverage of orbits with an inclination of 34 degrees to 51 degrees would be much improved. Future, piloted, Earth-orbiting flights were very much in the minds of the planners at the time.[9] In retrospect, their foresight was well justified since these locations effectively served the needs of the major tracking stations of the Deep Space Network for over forty years.

In the turmoil of space-related activity in that tumultuous year, 1958, ARPA never did get the opportunity to deploy the overseas stations of its World Net. NASA was created in October of that year, JPL was transferred to NASA in December, Pioneer 3 was launched, and by the opening of the new year, 1959, it was NASA and not ARPA setting the course for JPL and the future shape of the Deep Space Network. It was NASA that ultimately acquired and erected the two remaining antennas procured by ARPA. To the nation's space program, and to the work at JPL, the formation of NASA was transparent. It was mainly a transfer of authority and funding for the existing programs. Instead of working under an Army Contract, JPL now worked under a NASA contract. NASA inherited JPL's experienced personnel its facilities, including the new antenna at Goldstone and, perhaps most important of all, the JPL vision of a worldwide network of tracking stations for deep space probes. ARPA, representing military interests in space applications, pressed forward with its own programs under the direction of DOD.

As soon as NASA began to make its long-range plans for a civilian space program known, the need for completion of what ARPA had called the World Net immediately became obvious. One station already existed at Goldstone and sites had been proposed for two overseas stations. The antenna at Goldstone now belonged to NASA, but ARPA still owned the remaining two of the three originally ordered from Blaw-Knox. In January 1959, NASA and ARPA representatives decided each agency would get one antenna. The NASA antenna would be shipped to Australia as part of a three-station NASA operated network with sites in Goldstone (existing), South Africa, and Australia. ARPA would use its antenna as part of a deep space network for military purposes with stations in Japan and Spain. However, the military interest in deep space soon faded and NASA was eventually able to purchase the third antenna from ARPA to form the basis for its station in South Africa.

In moving toward the ultimate creation of the worldwide network, NASA directed its principal efforts in 1959 toward onsite surveys of the locations that had been proposed for Australia and South Africa and the diplomatic negotiations that were necessary to secure approval for their use.[10] In both countries, NASA was able to secure the interest of the government agencies—Australian Department of Supply (DOS)/Weapons Research Establishment (WRE) and the South African Council for Scientific and Industrial Research (CSIR)/National Institute of Telecommunications Research (NITR), respectively—in cooperating in the operation of the proposed deep space stations. Both WRE and NITR assisted the NASA/JPL survey team in identifying sites for the stations which met the three major criteria; a stable land area capable of supporting large antenna structures, surrounding hilly terrain to provide natural shielding against electrical interference and a surrounding area relatively free of radio interference in the frequency region useful for space communications.

WOOMERA, AUSTRALIA

The favored Australian site lay on the southern edge of the great inland desert region at a place called Woomera, about 350 kilometers north of the city of Adelaide, capital of the state of South Australia. Approximately 110 degrees west of the longitude of Goldstone, Woomera was already a missile and long-range rocket test center operated by WRE. The local language was English, and the nearby rocket and missile test activities would provide a pool of technical expertise and facilities. Furthermore, in the same area, the Australians had already installed, and were operating, a U.S. Navy minitrack station and a Smithsonian Baker-Nunn tracking camera as part of its participation in the IGY.

The signing of a "construction and operation" contract for the antenna around early April 1960 allowed both JPL and WRE to begin making major moves toward construction of a NASA deep space tracking station at Woomera. WRE initiated the road, buildings, power generation, and foundation work. JPL began shipping antenna components and the electronics for the station.

The antenna was finally built at a site known locally as "Island Lagoon," so named for the nearby dry lake which appeared to have an island at the center. Working under a JPL contract with supervisor Floyd W. Stoller, Blaw-Knox began assembling and erecting the antenna in May 1960. By August, the antenna was complete and an electronics team began installing the radio and tracking equipment, most of which had been supplied by Collins Radio Company. When NASA built the second and third 26-m antennas in Woomera, Australia, and Johannesburg, South Africa, the task of integrating the new antennas with their electronics equipment and bringing the two new stations into operation fell to Richard "Dick" Mallis.

Richard Mallis was an outgoing individual, easy to work with, sociable, and much respected by his colleagues. He was an excellent manager with good communications and technical skills and an appreciation for the different institutional environments at all three antenna locations. When he went to JPL in 1955 to work on radio guidance systems for the Army's Sergeant missile program, native Californian Richard K. Mallis took with him a degree in mechanical engineering from the University of Southern California and a Navy background. Caught up in the changes that swept JPL into the space program in 1958, he assisted with the construction of the first 26-m antenna at Goldstone, and later implemented the down-range tracking station in Puerto Rico to cover the launches of the Army's two Pioneer lunar probes.

Together with Goldstone, the three stations of the Deep Space Instrumentation Facility finally formed a worldwide network. With these completed in time to support JPL's first Ranger lunar missions, Mallis returned to JPL to take up a staff position in Renzetti's new Communications Engineering and Operations Section. He was responsible for Operations, regulating the way the Network carried out its day-to-day tracking functions. In this role, he set-up a Network-wide logistics and repair program, a frequency and timing standards program, a documentation system, and a training program for operations and maintenance personnel. This essential infrastructure remained the basis for all operations, maintenance, quality control, and configuration management processes as the worldwide Network expanded in size and capability through the years. He integrated the first commercial contractor, Bendix Field Engineering Corporation, into the DSIF as the operations and maintenance service provider for the Goldstone facility. In later years, as his responsibilities expanded to include the Space Flight Operations Facility at JPL in addition to the DSN, he became Manager of the Operations Division. Eventually he transferred elsewhere in JPL to further his professional career. However, because of his unique experience with service contract management, he was frequently called upon to assist the DSN in evaluating new contract proposals when existing service contracts expired. He retired in 1993 after 37 years of service at JPL and later took up residence in Australia.

In a final spectacular exercise on 3 November 1960, the Woomera station demonstrated its operational status by receiving voice and teletype messages transmitted from Goldstone via reflection from the Moon. The JPL onsite manager, Richard K. Mallis, departed Woomera four days later, after turning the new facility over to WRE for its future management and operation. The Australian engineers soon demonstrated their ability to handle the technical complexities of the new "space age" facility for which they had accepted operational responsibility. In a repeat of the "Moon bounce" experiment on 10 February 1961, during the official opening formalities, the station passed a congratulatory message from NASA Deputy Administrator Hugh Dryden in Washington to Australian Minister of Supply Alan Hume at Woomera over a "Moon bounce" communications link.

The photograph of the completed Woomera Tracking Station in Figure 1-6 shows the 26-meter-diameter antenna, the electronics equipment building, and service and facility structures. Island Lagoon is visible at the horizon to the left of the antenna structure.

The first overseas station of the Deep Space Instrumentation Facility (DSIF) was ready to enter operational service. Designated DSIF 41, Woomera, it would see eleven years of valuable service before being superseded by new stations at Tidbinbilla, near Canberra,

Figure 1-6. The 26-meter antenna and tracking station (DSIF 41), Woomera, Australia, 1961.

in southeast Australia. The Woomera station ceased operations on 22 December 1972, as part of a NASA program to consolidate overseas station facilities. Initial proposals to move the antenna to a new, more accessible location where it could be used for Australian radio astronomy purposes were not successful because the Department of Supply determined that the cost of transporting the antenna was excessive. Eventually, it was dismantled and sold for scrap despite the vigorous protests of several prominent members of the Australian scientific community.

JOHANNESBURG, SOUTH AFRICA

The requirements for continuous tracking coverage of deep space probes outlined in the JPL proposals for a worldwide network dictated that the third element in the network should be located in the longitude band which included Spain and South Africa. Although a site in Spain was preferred by NASA/JPL, the political complexities associated with existing international treaties with Spain caused NASA/JPL to look to South Africa for a suitable site. South Africa also offered many advantages. The South African government was anxious to participate with NASA in the new space venture, the language was familiar, and a great deal of technical expertise was already available in that country. Also, and most importantly, the flight path of all deep space probes launched from Cape Canaveral would pass over or near the station within an hour or so of launch. This meant that the downlink from the space probe could be first "acquired" close to the point at which the spacecraft would be injected into its planetary trajectory. During this period, mission controllers depended on telemetry and navigation data from the first acquiring tracking station to make critical decisions very early in the mission, when corrective action is necessary. Supplemented with the mobile tracking station that would be moved from Puerto Rico, an 85-foot antenna at this site would provide the DSIF with an excellent "initial acquisition" capability in addition to the normal tracking capability of the station.

The site that was chosen lay near the Hartebeestpoort Dam about 40 miles north of Johannesburg, on government-owned property intended for use as a radio research facility. As had been the case at Woomera, a NASA Minitrack station and a Baker-Nunn camera were already operating in the vicinity. An earlier site survey confirmed that the Hartebeestpoort site also satisfied the antenna site-selection criteria.

Although site surveys conducted in mid-1958 had confirmed the suitability of the site for the antenna, it was not until September 1960 that an agreement between the governments of the United States and the Union of South Africa permitted NASA to issue a contract to the South African Council for Scientific and Industrial Research for the construction, management, and operation of the station. NASA wanted the station to be completed by July 1961 in time to support the first launch of new Ranger missions to the Moon. Time was truly "of the essence." To prepare the site, erect the antenna, install and test the equipment, and train personnel in its operation, under the pressure of a high profile mission like Ranger, posed a formidable challenge for everyone involved.

Work began in earnest in mid-January 1961, as soon as the foundation for the antenna was ready. Antenna structural components travelling by ship, train, and truck from

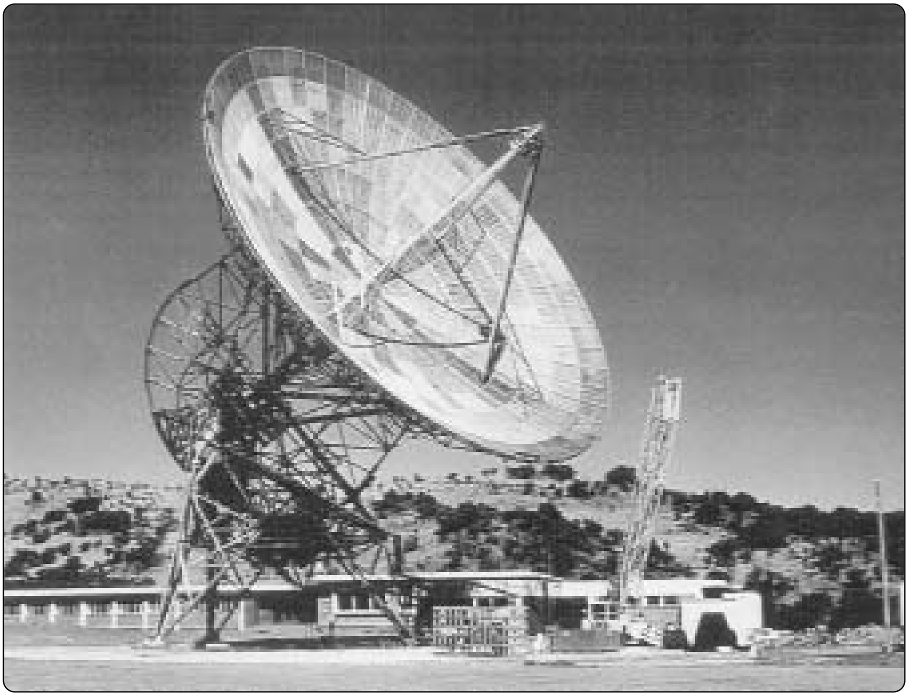

Figure 1-7. The 26-meter antenna and tracking station (DSIF 51), Hartebeestpoort, South Africa, 1961.

Philadelphia had arrived a few days earlier. The erection team arrived from JPL a few days later. Erection of the antenna finally began on 16 January and was completed 69 days later on 25 March. The JPL team—Don Meyer, Dick McKee, and Howard Olsen—completed installation of the electronics in early June and spent the next few weeks conducting the necessary tests, checkouts, and calibrations. The station was ready for operation by 1 July 1961. Provided with teletype equipment and communication circuits by the South African Department of the Postmaster General, the new station was able to participate in the first operational readiness test for the Ranger missions later in July, as originally planned.

A photograph of the Johannesburg Tracking Station soon after its completion in 1961 is shown in Figure 1-7.

JPL and South African officials discussed the possibility of holding a public event to mark the formal opening of the station as had been done for the Woomera station. There was, however, some reluctance on the part of NASA Headquarters to publicly recognize a cooperative project with South Africa in light of the United States' attitude toward the political situation then emerging in that country. Eventually, the South African government held its own opening ceremony without formal NASA representation. Some years later, this issue would intensify and ultimately lead to the closure of the station as a part of the Deep Space Network.

Nevertheless, the new station, designated DSIF 51, Johannesburg, played a vital role in the early NASA missions to the Moon and planets. In that role, it served the DSN with distinction for 13 years until DSN operations at that site were terminated in June 1974. Soon after, NASA transferred the antenna and equipment to the South African National Institute for Telecommunications Research (NITR) where it was used successfully for at least another 25 years, as an instrument for radio astronomy research.[11]

The completion of the Johannesburg station marked the fulfillment of the world network initiatives proposed years earlier by JPL, carried forward under ARPA, and brought to fruition under NASA. Together with a small launch monitoring facility at Cape Canaveral, the three 85-foot antennas at Goldstone, Woomera, and Johannesburg became known as the Deep Space Instrumentation Facility (DSIF). The DSIF had become a separate facility of the NASA Office of Space Operations. It was managed, technically directed, and operated by the Jet Propulsion Laboratory (JPL) for the California Institute of Technology (Caltech), a prime contractor for NASA's Solar System Exploration program, in Pasadena, California. Within a few years, the DSIF would change its name to the Deep Space Network (DSN) and rapidly increase in size, complexity, and capability to a level unimaginable to its founders. But that lay in the distant future. In the immediate future lay the first operational challenge for the new network—the Ranger missions to the Moon and the first Mariner missions to Venus. It was to be a busy future. The Mariner Era was about to begin.

Endnotes

1. N. A. Renzetti et al., "A History of the Deep Space Network from Inception to 1 January 1969." JPL Technical Report TR (September 1971): 32–1533.

2. William R. Corliss, "A History of the Deep Space Network" (Washington, DC: National Aeronautics and Space Administration CR-151915, 1976).

3. R. Cargill Hall, *Lunar Impact: A History of Project Ranger* (Washington, DC: National Aeronautics and Space Administration, 1977).

4. Homer E. Newell, *Beyond the Atmosphere; Early Years of Space Science* (Washington, DC: National Aeronautics and Space Administration SP-4211, 1980).

5. E. Rechtin and R. Jaffe, "The Design and Performance of Phase-Lock Circuits," *IRE Transactions on Information Theory* (March 1955).

6. Andrew J. Butrica, *To See the Unseen, A History of Planetary Radar Astronomy* (Washington, DC: National Aeronautics and Space Administration SP-4218, 1996): 42.

7. Jet Propulsion Laboratory, "Az-El Move and Reinstallation," *JPL Space Programs Summary 37-13* (Vol. III, 1 October 1962): 9–13.

8. Jet Propulsion Laboratory, *Description of World Network for Radio Tracking of Space Vehicles* (Pasadena, CA: JPL Publication No. 135, 1 July 1958).

9. E. Rechtin, H. L. Richter, Jr., and W. K. Victor, "National Ground-Based Surveillance Complex." JPL Technical Memorandum TM 39-9 (15 December 1958).

10. Support for NASA facilities in Australia, South Africa, and Spain was provided under cooperative international agreements between the United States and those sovereign countries. The diplomatic, political, and administrative complexities of the negotiations that culminated in those agreements is beyond the scope of this history of the Deep Space Network. Readers interested in pursuing those details will find useful material in the JPL and NASA Archives.

11. A more detailed account of many of the topics discussed in this chapter is contained in the unfinished and unpublished notes on the early (prior to 1962) history of the Deep Space Network compiled by Craig Waff at JPL in 1993. The Waff notes are held in the JPL Archives.